THE DEVELOPMENT OF ELECTRIC TRACTION

BY

ROBERT JOSEPH MALCOLMSON

THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

RAILWAY ELECTRICAL ENGINEERING

SCHOOL OF ENGINEERING

UNIVERSITY OF ILLINOIS

1922

UNIVERSITY OF ILLINOIS

June 1, 1922

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

ROBERT JOSEPH MALCOLMSON

ENTITLED THE DEVELOPMENT OF ELECTRIC TRACTION

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Railway Electrical Engineering

J. K. Tuthill
Instructor in Charge

APPROVED: Edward C. Schmidt

HEAD OF DEPARTMENT OF Railway Engineering

C O N T E N T S

A C K N O W L E D G E M E N T

In writing this thesis,I have received valuable and authentic information from both the Westinghouse and General Electric Companies. These two companies have been very generous with their information regarding Electric Traction and Locomotives.

I also received much help from the trade publications such as the Railway Age Gazette; Railway Mechanical Engineer; Electric Journal; Electric Railway Journal; Railway Review; Engineering News; Engineer (London); Electrician; Railway Age.

I N T R O D U C T I O N

Electric Traction today holds a commanding and deserving position in the transportation and expansion systems of the world. Much has been written of modern electric locomotives and there has been wide spread interest in the problem of electrification of main trunk lines in the world's railways.

These massive modern electric locomotives that have almost undreamed of capacities have gone thru and exceedingly interesting development. Hardly twenty years ago they had not even started their development, yet today they are a mighty contender with the long established steam locomotive for the world's commerce.

This thesis is written in order to give a clearer and more definate knowledge of the evolution of the electric locomotive. Its primary interest is to show the development of the locomotive itself rather than the development of electric systems.

INTRODUCTION

Steam railroad electrification has received wide-spread attention during the last two years through the extensive advertising of one of our western railroads for the purpose of popularizing their line with transcontinental passengers.

The public is quick to grasp an opportunity for a new thrill or novelty, but seldom analyzes the conditions involved.

Steam railroad electrification is an expensive undertaking, and railroads cannot be expected to electrify their lines as a refinement and convenience to the public. The changes must be justified from a financial standpoint.

Such a change in operating methods involves a thorough study of the particular problem with which each railroad is confronted. The possibilities of electrification are not centered about the general superiority of the electric locomotive over the steam locomotive. The railroads of the United States are, without question, the standard of the world, and we have nothing but admiration for the magnificent performance of the modern steam locomotive.

In this thesis then, the replacement of steam operation by electric power will be considered from the same view point and same reason which caused it to be adopted in other large industries; namely, the flexibility of the electric system which permits improvements in operating methods with resultant decrease in operating cost and increased production. Under present methods of efficient railroading, involving constantly increasing size of trains and faster schedules, the steam locomotive, due to the fact that it is a self-contained

unit, must soon reach its limitations in horse power rating.

On the other hand, the electric locomotive, which does not generate its own power, but simply transforms electrical energy to draw bar pull,has a great advantage when problems of economical handling of heavy traffic on mountain grades at efficient speed are considered.

This is well illustrated in this thesis in the description of the most powerful locomotive of its kind ever produced for railway work. The concentration of 7000 HP for starting trains and 4800 HP for hauling them, in a total weight of 250 tons and a single cab 76 feet long, is a step in advance of anything heretofore accomplished. It means that larger trains can be handled over grade at a higher speed and with minimum operating expenses.

With this in mind, the thesis considers the electrification question and its development.

BRIEF HISTORY OF ELECTRIC TRACTION

The history of electric traction for railway train servive is taken up in order to understand the progress which has been made during the past twenty years in transportation methods and to understand the service condition surrounding the application of electric power. In this survey a proper view point of the question will be gained, and the problem before some of the railway companies can be understood.

The history of transportation shows clearly the improvement of motive power and method are obtained only by slow development and careful experiment. In a study of railway electrical engineering development, it is always well to require specific knowledge on approved modern engineering methods.

The years 1830 to 1860 mark the first period of experiment dealing with the application of electrical energy to transportation. During this period most of the work was limited to application of permanent magnet and reciprocating motion. A limiting feature that hindered further progress was the capacity and lack of serviceability from chemical batteries.

Thomas Davenport of Vermont made many models of electric railway motor cars in 1835 which had batteries as prime movers. Third rail conduction and track return circuits were used.[1]

One of the first of the large units to be built was a seven-ton two-axle car for the Edinburg Glasgow Railway. This was constructed in 1842 by Davidson. Four electromagnets were used in pairs on each side of a wooden cylinder carried on each axle and fastened with

1. Electrical World, October 6, 1910.

three bars of iron parallel to the axle. Current was produced by an iron zinc sulphuric acid battery. The electromagnets attracted the bars on the cylinder, then the current was alternately cut on and off, thus producing rotation. A speed of four miles per hour was attained.

In 1847 Lilley and Cotton operated cars making use of the alternate attraction and repulsion of magnets to produce motion.

In 1851 a 100-cell nitric acid battery car appeared in Washington, D. C. C. G. Page was the designer, and his car received motion from two solenoids, or hollow magnets, which alternately attracted cores on a plunger. This reciprocating motion was transmitted to the wheels by means of a crank. A speed of 19 m.p.h. was attained--yet few improvements had been made.

Dynamos, or electric generators, began to develop between 1860 and 1866, but it was some time before it was discovered that an electric generator could drive a similar machine, now called an electric motor.

Farmer operated a car with motors and dynamos in 1867; while in 1879 Siemens and Halske, at the Berlin, Indiana, Exhibition propelled a minature locomotive and three cars with electric power from a dynamo. The track rails, 1000 feet long, formed a 160-volt circuit. Spur and bevel gear were used to transmit the power from a three- horse power motor.

Thomas A. Edison ran a small locomotive in Menlo Park, New jersey, in 1880. A dynamo was the source of his power.

Stephen Field (1880), Siemen (1881), Van Depoile (1883-1884), made slight improvements.

The field of development of public street cars (1880-1888) will

not be touched in this paper but rather the development of the electric locomotive.

Early electric locomotives were crude and poorly adapted forms of motors. The Northern Pacific Railroad contracted for an electric locomotive for freight service in the Dakotas. It was equipped by Edison with a series belted 220 volt, 10 horse power motor, and hauled a three-car train, power being supplied through the two track rails.

In 1883 Edison and Field operated a geared and belted three-ton electric locomotive, "The Judge," using a third rail contact line. A Weston dynamo and motor were used.

Daft made some development in operating locomotives with double belted, 130 volt, 15 horse power motor and a third rail.

In 1893 the Westinghouse Company built a locomotive for the North American Company. The locomotive weighed sixty tons. There were four sets of 56-inch coupled drivers, rigid wheel bars 15 feet, driving connection through gearing. The motors used were four 300 horse power Westinghouse iron clad type, 225 r.p.m. D.C. 800 volt, 250 amp. units. Series parallel control was used. Magnets were compound wound, but the shunt field had only sufficient turns to keep the speed within reasonable limits at light loads. The motors were designed for regeneration.

MOTOR CAR TRAINS

Defined, a motor car train is a group of mechanically connected cars equipped with and propelled by electric motors under some or all of the cars on the train.

Since 1885 single truck motor cars frequently have hauled light trailers for heavy morning and evening street car service.

At first there was one 50 horse power motor on each truck, but the weight on the drivers was not sufficient and the wheels slipped, causing a waste of time and power. About 1898 to 1900, four motor equipments were adopted. The limit in seating capacity for suburban cars was soon reached, because when a car was longer than 55 feet, short radius curves at street intersections were impossible to be made. Two car trains, motor and coach, operated by motormen, came in.

A Ten-Car Multiple-Unit Train—New York, Westchester and Boston Railway

ELECTRIC LOCOMOTIVE CHARACTERISTICS

In general, electric locomotives may be classified as of two types; variable speed and constant speed. The variable speed employs the series motor, which possesses the inherent characteristic that, other conditions remaining the same, the speed varies automatically with the load. The constant speed type of locomotive employs the polyphase induction motors such that the speed is constant for all loads.

Variable speed motors may be either the direct or the alternating current type. Constant speed motors operate from alternating current only when an induction type of motor is employed.

The weight of an electric locomotive depends primarily on type of service and capacity. There are two general classes; one with the locomotive weight on the drivers, the other with a portion of the weight carried on a bogie truck or pony. High powered locomotives are inherently heavier than those developing less power at the same speed. Within reasonable limits, locomotives may be built for the same speed in both classes.

Steam locomotives require repair shops, round houses for frequent washing of flues, and stations distributed along the line with machinery to store and handle the coal and pump the water to the tanks.

The physical advantages of the electric locomotive arise from the inherent characteristics of electric motive power. Capacity is the most important of these advantages because capacity bears directly on economy of train operation. The capacity of the steam locomotive is limited. There is reasonable objection to the heavy

and complicated mallet compound if a simple and efficient design of electric locomotive, unlimited by track gauge, is available.

Increased locomotive capacity offers immediate relief from congested traffic conditions that seem hopeless under existing circumstances. A modern steam locomotive is a splendid piece of apparatus, but, when conditions of service have grown beyond what can be handled efficiently by the steam locomotive, the powerful electric locomotive steps in and takes up the task and solves some of the railroad problems. "Whenever traffic is dense enough, electric traction not only materially decreases the operating cost per ton mile, but either accomplishes this end with a material decrease in the motive power equipment, or can handle fifty percent more traffic than can be handled under the most favorable conditions of steam operation"--Graham, Vice President, Erie Railroad.

Capacity is available with electric traction because the source of energy is large central stations, where for important service and heavy grades, ample power and great temporary overload may be advantageously employed. Steam operated locomotive has its own source of power upon its back. The electric locomotive has a power station behind it.

The backbone of the railway business, the freight traffic, now calls for heavier trains and faster schedules. Railway managers demand this because expenses are per ton mile and train hour. This demand cannot be met by the steam locomotive, for its capacity and weight per ton of wheel base has reached uneconomical and undesirable limits.

Capacity is all important in railroading, for the public and for the investor. Service is always demanded, to transport freight

and passengers rapidly, and a very heavy train is required.

Capacity results from draw bar pull, its quality and amount; acceleration rates, the speed utilized, the mileage of the locomotive, and the power developed per ton mile.

ELECTRIC LOCOMOTIVE DRIVES

The drive for electric locomotives, the means whereby the torque of the motor is transmitted to the driving wheels, constitutes one of the most involved problems in electric locomotive design. The reasons for these conditions are many. They can be traced to the earliest history of the steam locomotive. Since electric locomotives must be constructed to meet the clearance requirements of the trunk line railroads, the question of space limitation and standard clearance constitutes the first of the involved problems of design. A steel railroad track does not present to the train the smooth surface that it appears to be. It is really a highly cushioned yielding structure. The question of track effects and the pounding of the motors must be carefully considered. The suspension of the weights of the locomotive and the total amount of dead weight to be allowed on the track are all important. No track will stand too severe a strain, nor will the motors stand too severe pounding and vibration. The method of transmitting this power, or energy, from the torque of the motor to the creative effort at the tread of the wheel, then constitutes that most important problem of locomotive drive design. Gear reduction, lengths of armature, and possibilities of coupled drives must be considered. It is not possible to go into detail regarding the design for the locomotive drives at this time. A A brief description of the various types of drives that are in actual use can be made and will give a fairly good and general idea of the mechanism and methods of transmitting the motor torque to the tread torque.

METHODS OF DRIVES FOR ELECTRIC LOCOMOTIVES

The fundamental function of a locomotive is to transform energy into draw bar pull and speed or stated in a different way, it is the delivery of transportation. Locomotive drive is the mechanism transmitting the armature torque to the rail. The function of electric locomotive drives is, therefore, to transmit and transform the tangent force at the air gap of the propelling motors to the tangental force at the tread of the drivers. The drive should be performed with safety, reliability, and in such a manner as to give the minimum operating expenses. Low locomotive maintenance is important.

Three fundamental principles are

1. Locomotive maintenance is an unreliable measure of overall railroad maintenance.

2. The locomotive type which is to endure must be easy on the track vertically.

3. The locomotive must be easy on the track transversely.

The simplest form of geared drive used is shown in Fig. 1. Each driving axle is equipped with a motor mounted as on a street car or interurban car, the detail being familiar enough without discussion. Electric locomotives with this general type of drive are in service with both rigid and flexible gears, and with gears at one or both ends of the motor.

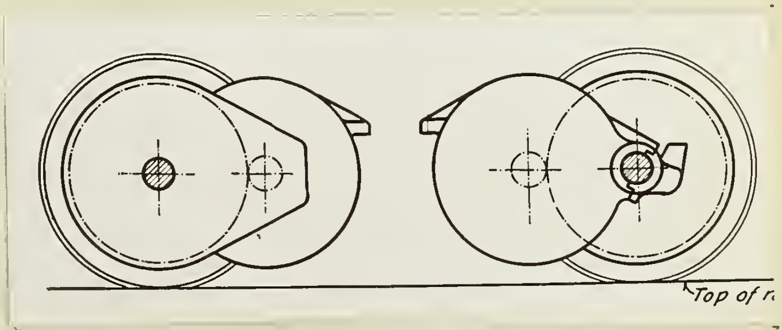


Fig. 1. Direct geared motor drive.

The construction of a flexible gear is shown in Fig. 2 . It consists of three fundamental parts; a center, an independent rim, and tangentially disposed spring members. These spring members co-operate with lugs on the center and rim in breach block assembly.

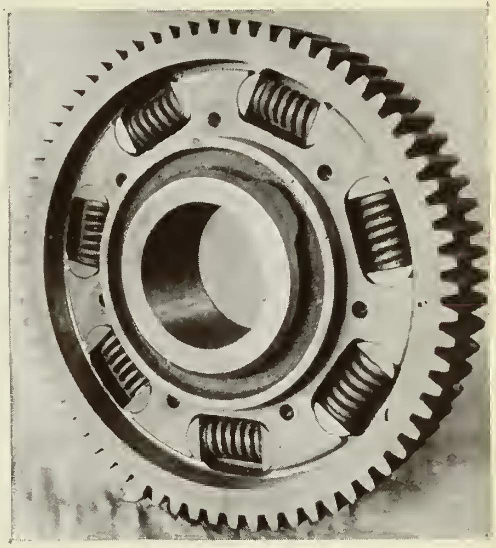


Fig. 2. Helical gear.

Flexible gears were first used commercially on electric motive power on the New York, New Haven, and Hartford Railway, being followed by the Boston and Maine locomotives and the Pennsylvania cars. Since then the operation has been successful enough to warrant their use on other large locomotives.

The flexible gear inherently involves a large labor charge, and consequently it is desirable to take precautions to insure longer life. The best gears are hardened and their internal working surfaces ground.

Ordinarily about five-eights of the motor weight is carried on the axle bearing, the remaining three-eights being carried by the motor nose. This type of drive is, therefore, imposes heavy stress on the track due to the great dead weight on the driving axles. The result is a sacrifice roadway and track maintenance to gain low locomotive maintenance.

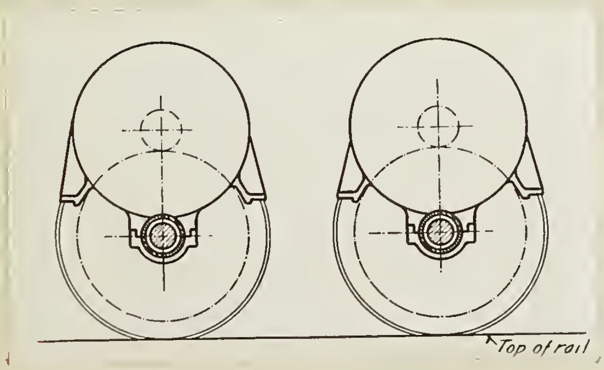


Fig. 3. Single armature gear and quill drive.

The drive known as the single armature Gear and Quill drive is shown in Fig. 3. A motor is

mounted solidly on the spring. The frame of this motor includes two bearings carrying a hollow shaft or quill which surrounds the axle (driving axle). At each end of the quill a gear is mounted meshing with the motor pinions.

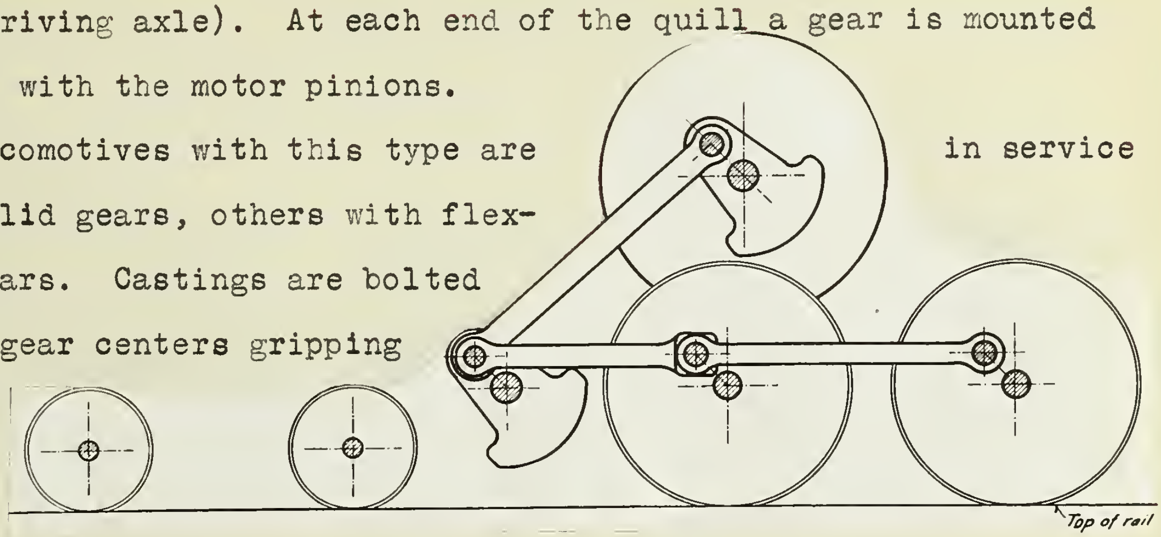


Fig. 4. Side rod drive.

Locomotives with this type are in service with solid gears, others with flexible gears. Castings are bolted to the gear centers gripping the end of the helical springs, which are located between the wheel spokes. The other end of the spring is gripped in a casting which is bolted to the driving wheel. The springs serve the purpose of permitting vertical wheel displacement without serious restraint on the motors and also work in series with the gear springs in cushioning angular displacement of the gear.

The quill drive needs a larger driving wheel than the direct drive on account of the large diameter of the quill. As operating speed increases, the gear dimensions decrease in order to secure the proper gear reduction. The quill drive then lends itself very well to a well balanced locomotive design with reasonable locomotive maintenance and low roadway and track maintenance. During the early development of the quill drives the spring maintenance was rather high. Experience has proven that adequate design is feasible and maintenance

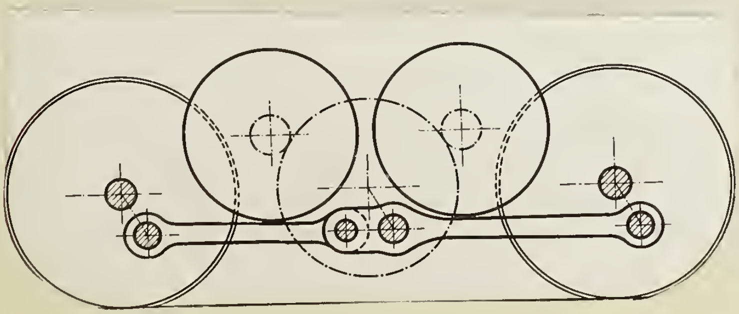


Fig. 5. Gear and side rod drive.

of this type of drive is now low.

This type of drive lends itself to a somewhat shorter wheel base than is feasible with the direct-geared motor. This is particularly desirable when more than two axles are mounted on the rigid wheel base.

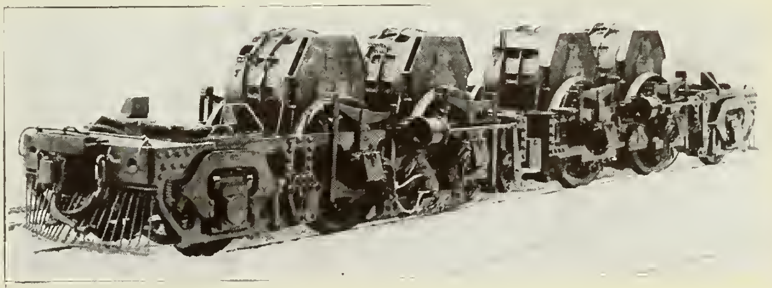


Fig. 6.

The twin armature gear and quill drive is different from the single armature drive in the method of armature and gear arrangement. The twin armature type is fitter with a single gear meshing with two pinions, one on each end of the armature shaft. The single gear may be of the same width of each of the gears in the single armature type. This leaves considerable length available for the active iron of the armature. From the standpoint of flexible drive there are two marginal advantages inherent in the twin armature arrangement.

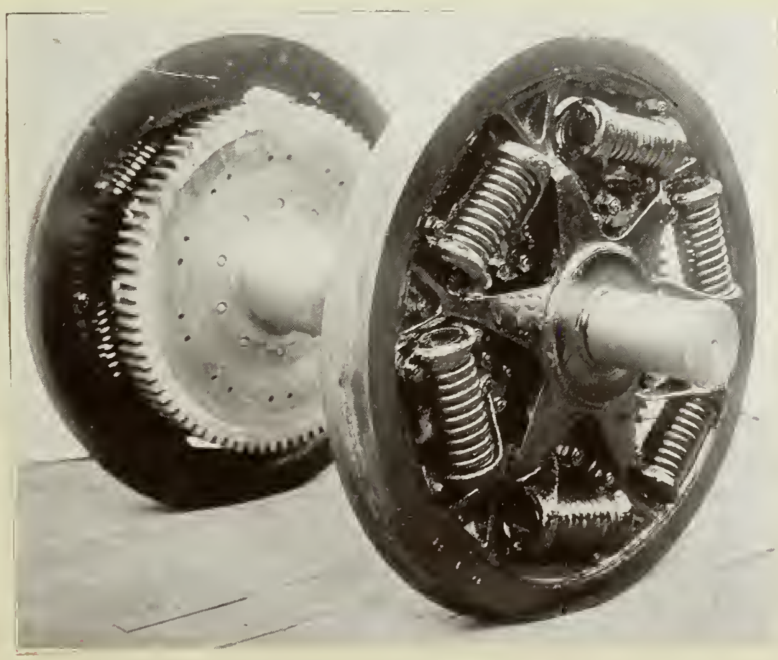


Fig. 7.

In the twin drive the two pinions equalize properly on the single rigid gear quill drive, satisfactorily cushioning angular displacement. The gear of the twin drive is rigid. As far as the quill drive details are concerned, the twin armature type gives great-

er driving axle load with equal margins of safety. The maintenance of drive detail is less than with the twin armature type.

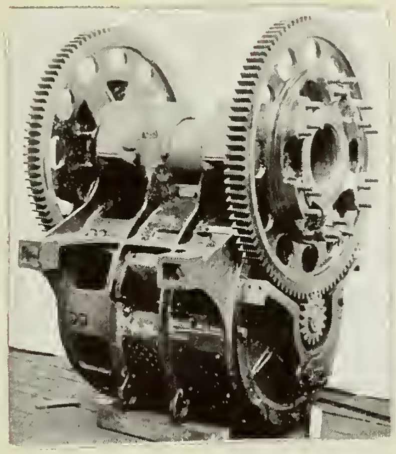


Fig. 8.

Fig. 6 shows a type of side rod. The motor is rigidly mounted on the spring supported framing of the locomotive. The only difference is that the motor is high and is practically releived of the length limit set by the distance between the back of the wheels.

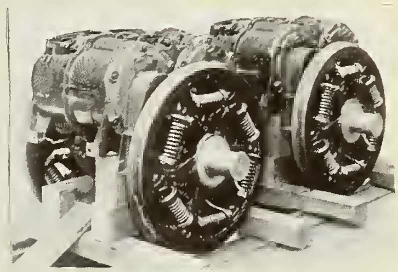


Fig. 9.

The motor shaft is fitted with quartered cranks. The tractive effort is transmitted by inclined side rods to a jacket whose bearings are rigidly mounted in the locomotive framing at the level of the driving axles. Rod coupled drivers offer important and fundamental advantages over independently driven axles in addition to those previously mentioned.

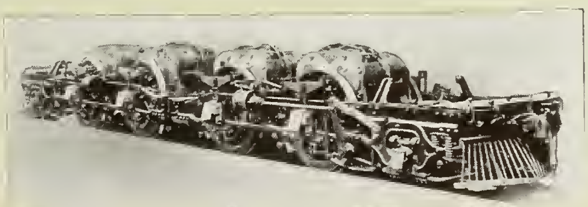


Fig. 10.

When the axles are independently driven, the mechanical couple offered by the draw bar pull at the coupler and the reaction of the truck body gives the greatest possible tractive effort.

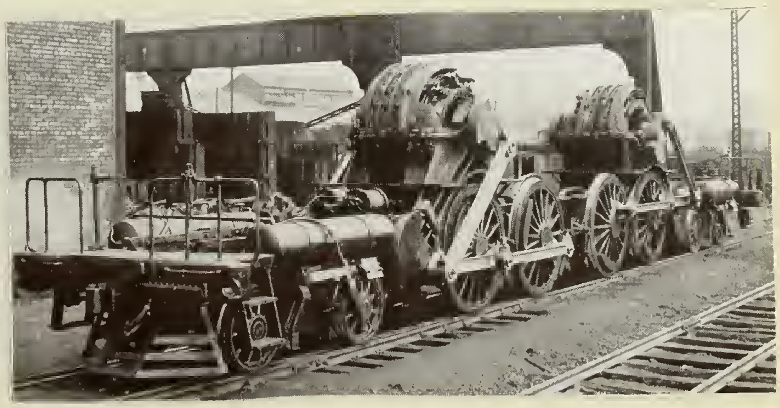


Fig. 11.

This is a decided advantage since it minimizes the danger of blocking traffic. For heavy high speed passenger service this type of

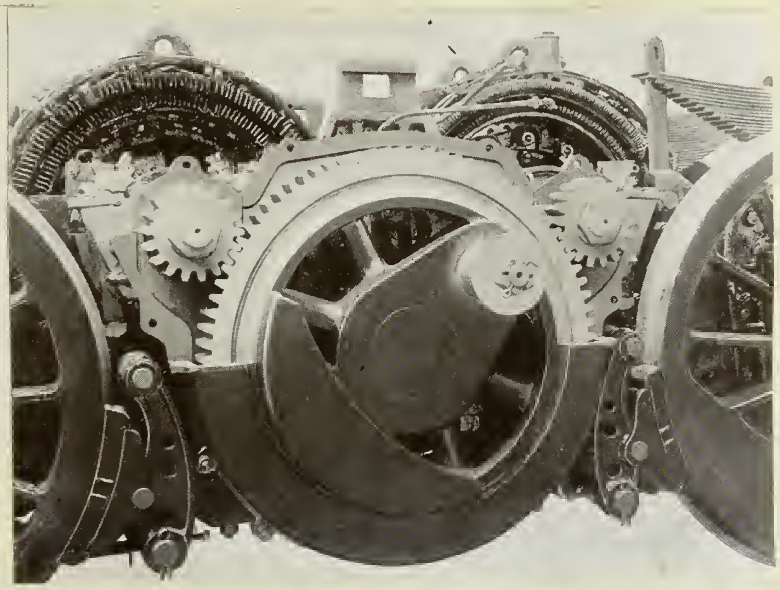


Fig. 12 A.

locomotive is being used extensively, especially by the Westinghouse Company.

Gears and side rods. The types discussed above lend themselves to either single phase or to direct current electrification. The type shown in Fig. 8 is particularly adopted for polyphase motors where the installation is simplified by adopting a small number of large motors, arranged in the minimum number of independently rotating groups. For freight drags, this type combines adhesion advan-

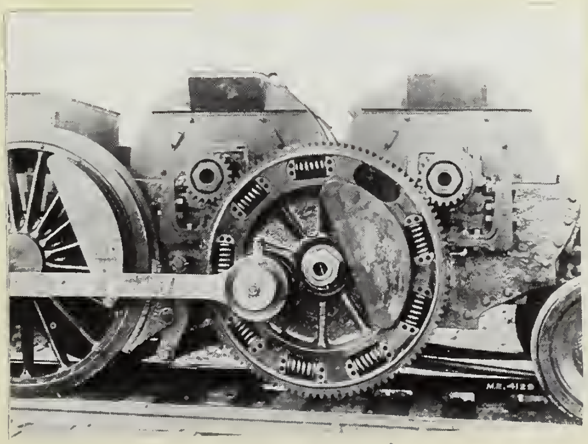


Fig. 12 B. Flexible gear on end of jack shaft.

tages with high armature speed at low locomotive speed. The dead weight per axle is at a minimum.

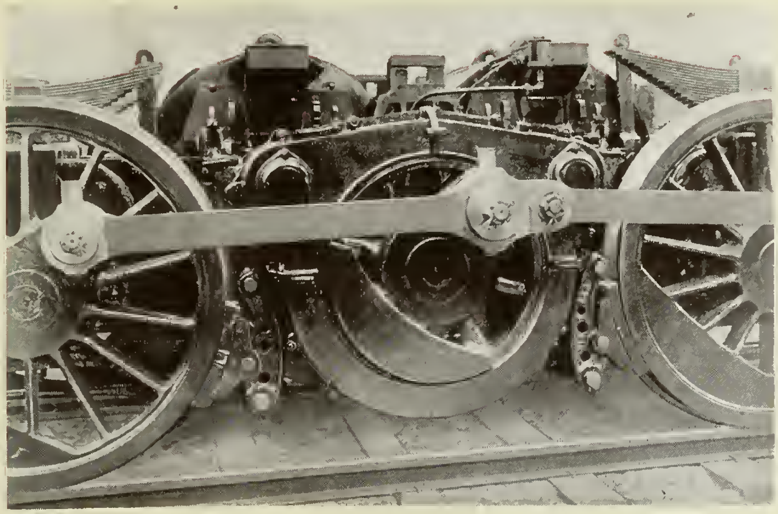


Fig. 13.

With this type it is possible to build a locomotive with two or three axles with the heaviest axle loading permissible on any existing track construction. The long mountain freight drag for which this type is adapted constitutes a drastic railroad service.

CONCLUSIONS. With increased electrification, the goal for all railroad operators and designers is jointly to developé a locomotive of reasonable cost that will deliver the maximum transportation safely and reliably with a minimum overall railroad maintenance.

Fig. .2 shows a type of flexible gear. This type is used on the New York, New Haven, and Hartford Railway. It consists of three parts: a center, which is a casting, a forged rim, and springs inserted in breech blocks between the tin tongues on the center. The function of the flexible gear is to relieve the peak loads on the motor. In addition to cushioning peak shocks, this gear will largely relieve the motor armature bearings, commutators, and brushes. Fig. 6 shows a type that puts the motor weight entirely above the semi-elliptic

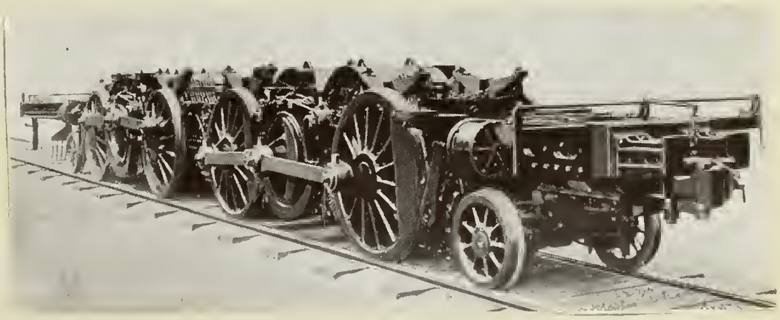


Fig. 14.

springs of the locomotive.

Fig. 7 is the New York, New Haven, and Hartford locomotive quill drive. The gears are mounted on what looks like the axle in the middle of the cut, pressed onto the quill surrounding the axle. One end of each spring is gripped solidly and the gripper castings are bolted to the gear center. Fig. 8 shows the quill bearings rigid with the motor frame. The motor feet are bolted to the frame of the locomotive, thus securing semi-elliptic spring support for the entire mass. The motor is rather heavy for its horse power. It sticks up a long way into the cab.

Fig 9 shows motors with identical quill construction, but instead of having a gear on each end just inside the wheel, there is a gear at only one end. These motors mounted on the locomotive are shown in Fig. 10. Fig. 11 shows a Pennsylvania terminal locomotive where side rods are used. Fig. 11 is another view of the same locomotive. Fig. 12 is a close up of the gear and side rod used on the Norfolk and Western. In this case there are gears on each side of the locomotive and two pinions on each gear with crank pins in the center. Fig. 13 shows the connecting rods in place. The jack shaft is cast in the framing. The jack shaft stands rather erect and high because the cab weight is not applied. It settles to very nearly the axle height when the upper weights are imposed, with little allowance for spring sag. Fig. 14 shows a general appearance.

Big wheels seem to be easier on the track. On the Norfolk and Western the size of the wheels is 62 inches, and the operating speed 28 m.p.h. From tests made on this road, the company advises big wheels as being easier on the road bed.

DEVELOPMENT OF ELECTRIC LOCOMOTIVE DESIGN

Modern electric locomotives for railway trains represent the culmination of numerous efforts in design, beginning early in the pioneer days when trials and experiments were made at Baltimore in 1895. A general review of the work done in this field will assist greatly in gaging the value and scope of the work done together with some of the features and periods of development through which electric traction has evolved.

Up to and even after 1905 there had been few attempts at standardization of frames or even of mechanical motion, either for freight or passenger service. Each new locomotive seemed to present a new idea and had many new features of design.

Since 1906 there has been a noticeable and rapid improvement in standardizing the character and the construction of the electric locomotive frame, trucks, wheels and drives. There is, however, no standard design that is strictly adhered to even at the present time (1922).

The development and progression of electric locomotive design has brought many mistakes that were made by early builders. This could be easily expected when we consider that early designers lacked experience, not appreciating the problems and desiring simplicity, there were many unsatisfactory compromises between steam and electric designers.

Some of the more serious mistakes made in early development were:

1. Low centers of gravity were used, causing curves to be slewed at high speeds.

2. Bearings on the motors were not long enough, and together with the heat from the motor they ran hot.

3. Motors were not accessible for inspection, nor easily removed from the locomotive for inspection.

4. Heavy dead weights were not spring mounted; tracks were destroyed and badly aligned in spots.

5. Power was concentrated on a short driver wheel base and strains were produced with great pressure and suddeness. The locomotives pitched and rolled.

6. Motor ratings were deceiving and misleading, causing much trouble and disappointments.

DESIGN OF ELECTRIC LOCOMOTIVES

A locomotive is primarily a hauling machine. Its design is defined by recognized limits such as maximum degree of track curvature, coefficient of adhesion between driving wheels and rails, gross dead weight per axle. The locomotive should be simple in construction, reliable in operation, and capable of being maintained in condition for a reasonable percentage of its cost.

In studying the development of Electric Traction, the progress made in the design of the electric locomotive is very important. It is the object of this chapter to give some of the important things that have confronted engineers in the design of electric locomotives. It is interesting to see the mistakes that were made and the many different types of construction. Later tendencies, that is within the last few years, are to standardize the design of the electric locomotive. Locomotives propelled by electricity are young, and there has not been enough time to perfect any standard design. With the ever increasing experience with electric traction, the mistakes of earlier designers are beginning to be seen and corrected, and it is safe to predict that within a very few years that electric locomotive design will be practically standardized.

The next few paragraphs will briefly review some of the more perplexing and more important developments of design. No attempt is made to go minutely into the question of design as that would be impractical as well as impossible in a survey of electric traction in such as this thesis is.

It is always important to keep in mind here that there is an

important element of difference between the development of the steam and electric locomotive. The former grew up with transportation; the latter had to be designed and put into immediate competition with a rival perfected thru decades of gradual evolution, The steam engine at present is making fast progress but on the whole its progress has been slow and steady. On the other hand, the electric locomotive is not more than 17 years old.

So the remarks one hears of occasional trouble with this or that electric locomotive makes him hastily conclude that this type of machine is not up to the job. Throughout this thesis it should be borne in mind that, in spite of some maintenance costs, the machine as a class is performing splendid service, often overloaded beyond reason and each day doing the work of several steam engines and doing this work better. Picture the electric locomotive today if it too, like the steam locomotive, could have started with transportation.

Many years of experience in operation of steam locomotives have resulted in the recognition of more or less standard design of its running gear and super structure. Minor differences existed to be sure, as to wheel arrangement and valve gear, but the side-rod drive, common to all steam locomotives, is the common means of transmitting the power of the expanding steam in the cylinder to the rotating drives.

The electric locomotive, on the contrary, presents a wide diversity in methods of drive. The extreme flexibility of the electric motor and its adaptability to many successful forms of construction account in part for the many different types of electric locomotives built. It is true that the type of motor adopted

whether it shall be D. C. or A. C. might impose limitations to the design. This is illustrated very strongly in the New york Central electric locomotives. The simplicity of the gearless driven D. C. locomotives here can be approximately reached with A. C. motors only by resorting to an undesirable combination of quill and spring drive. We may, therefore, look for the reason of unusual forms of construction not to any mechanical superiority or excellence offered by the design adopted but rather to the type of motor used.

It was natural that the earlier design of electric locomotives should follow the construction found successful in the operation of double truck motor car with four motors which drive the four axles through single gearing. There are many locomotives of this design, weighing from forty to sixty tons total, that have given long years of satisfactory service, and, for moderately operating speeds, this construction constitutes commonly accepted practice.

With the need of heavier freight locomotives, it was found desirable to introduce twin gear drives between motor and driving axle in order to equalize stress. There also came the introduction of the hinged joint between the two trucks constituting the running gear of the locomotive.

From the success that operation of the twin geared motor drive had from the first, it appears justifiable to look upon this form of construction as well adapted to meet the requirements of moderate-speed freight locomotive service. It would seem also that locomotives of large capacity demanded for heavy freight service can be built with this type of construction without exceeding accepted practice of weight limitations per axle. This statement applies only to D.C. electric locomotives, as the A.C. type must make ade-

quate provision for a transformed and possibly a phase converter in addition to the motor and control equipment.

The locomotive cab provides none too ample space in which properly to install direct current motor control air compressor, blower, etc. When in addition, space must be provided for the transformer and possibly the phase converter required with A. C. motors, which, themselves, may project up into the cab if side rod drive is used, then the limited cab space available makes it extremely difficult to locate the several pieces of apparatus so as to afford convenient access for inspection and repairs. Very large A. C. motor locomotives will probably require idle axles to carry the additional weight of the auxiliary control apparatus. The use of guiding axles on freight locomotives, therefore, may become more a question of type of motor used, whether A. C. or D. C., rather than due to any necessity to use such axles in order to get good riding qualities.

It may sometimes be overlooked that the whole argument for electrification rests upon the superior qualifications of the electric over the steam locomotive. The fundamental principle of design should, therefore, provide for the greater simplicity of motor construction and drive as well as afford ready access to wearing parts. Simplicity and accessibility both contribute to the reliability, high efficiency, and low cost of maintenance characteristic of the D. C. motor locomotive.

Two general types of construction appear to have demonstrated their fitness for freight and passenger service. In studying the types of electric locomotives that are now in operation, I think that they can be resolved into the two types mentioned here.

For heavy freight service a locomotive of approximately 200 tons weight upon the drivers is demanded. It should be capable of delivering continuously a T. E. of 16 percent of the weight of the drivers, or 64,000 pounds at a speed of approximately 15 m.p.h, (Largely from General Electric Company data). For convenience in making shop repairs, it seems to have been found desirable that this locomotive should be in two units of 100 tons each. Each unit is carried on two four wheel bogie trucks connected by a hinged joint. The motors should be cooled by forced draft and drive thru twin gears.

For high speed passenger service, a locomotive with superior riding qualities at 75 m.p.h. is desired. The simplicity of gearless construction is more fully appreciated in this class of service. The New York Central type of gearless locomotive can haul a 1000 ton train at a speed of 60 m.p.h. with an efficiency averaging 90 percent throughout its operating range. The D.C. is the only type of motor possessing the inherent qualification necessary for gearless construction and the high speed requirements can be particularly adopted by them.

There is as yet no general acceptance of a standard design of electric locomotive. Geared side rod construction for heavy freight service and twin motor gear to a quill for passenger locomotives appear to find favor with the Westinghouse and Baldwin engineers, while the General Electric goes in for the simple arrangement of geared axle motor for freight and gearless motor for passenger locomotives. In Switzerland and Italy the side rod enjoys an almost exclusive field.

DEVELOPMENT OF MECHANICAL DESIGN

The main features of mechanical design that have been developed are:

1. Safety of operation.
2. Adaptability to service conditions.
3. Reliability of service.
4. Convenience of arrangement as affecting safety and efficiency of operation.
5. Power efficiency (affected by mechanical design).
6. Service-time factor (ratio of time available for service to total time).
7. Cost of maintenance of permanent way.
8. Cost of maintenance of locomotives.
9. First cost.

SAFETY OF OPERATION

The steam locomotive is so perfected that it is common to see it operated at 80 m.p.h. forward, but not so backward.

With the coming of electric locomotives, railroad operators are not content with single end operation, but must operate either end equally well. This requirement does not impose serious difficulties in design under 50 m.p.h., but for high speed presents new problems; more careful consideration of the running gear details to obtain most satisfactory results as to backing and the effect on the rails and roadbed.

The advantages gained in operating the electric locomotive in either direction are so important that means should be provided for

satisfactory double end operation. One way to do this would be to use a four wheel guiding truck at each end of the locomotive. With the use of the extra truck, however, the importance of the high center of gravity largely disappears, according to General Electric designers. The lateral pressure against the rail at the rear end now appears at the truck flange rather than at the flange of the driving wheel. The high center of gravity no longer provides the same increased vertical pressure on the outer rail at the point of the maximum lateral pressure. The lateral stresses from guiding the main frame being taken at the center pin of the guiding trucks, the additional vertical pressure on the outer rails is dependent upon the height of these center pins rather than upon the height of the center of gravity of the main frame above the rail head, thus leaving less advantage to be derived from a high center of gravity.

The greater weight being concentrated at drivers, and the distance of the truck center pin from main truck wheels being greater, and the fact that there is but one wheel to take the strain, it follows that the point of the greatest concentrated lateral pressure is at the real outer driving wheel. On good road beds the locomotive described is capable of 80 m.p.h. with no bad effect on the track.

If the locomotive is operated in the opposite direction, the lateral stresses are of the reverse order, the guiding force now applied at the driving wheel flange and the reaction taken through the center pin to the truck wheel flange. The swivel truck, now trailing, is free to oscillate from one side to another, and the reaction from the force of turning the main frame may be applied at the center pin when the truck wheel flanges are tight against

the inner rail. This allows the force to accelerate the truck as well as the main frame through the gage clearance to the outer rail, thus adding momentum, the value of which depends upon the lateral distance through which the truck is moved, and, as the vertical pressure on the rail is limited to the normal weight at the wheels plus the vertical component of the force applied only at the height of the center pin of the truck, the relative lateral to the vertical pressure at the wheel of the truck may be greatly increased. A number of observations have appeared to confirm the fact that the action of the trailing truck above described is one of the most important in producing excessive lateral pressure against the rail in a symmetrically built electric locomotive with similar trucks at both ends.

It will be seen, therefore, that while the swivel truck is desirable as a guiding agent at the front end it is not as desirable at the rear end, and means must be provided to prevent oscillation of the truck and to accomplish the same results that the high center of gravity does in a single end locomotive.

To accomplish these results it is necessary to reduce the momentum effect and to reproduce the equivalent of the time element factor and of the increase of vertical pressure on the outer rail that is characteristic of the high center of gravity single end locomotives.

The momentum effect can be reduced by introducing resistance against swiveling, thus restricting the truck from oscillating from one side to the other of the track, the amount of this resistance to be determined by the allowable amount that can safely be applied to the truck when leading. To reproduce the time element factor

lateral movement can be given to the truck center pin by any of the several methods for giving lateral movement to the leading truck center pin on locomotives. Best results seem to have been obtained with the method that is nearest to constant pressure and dead beat, as it tends to prevent oscillating.(Mr. A. F. Batchelder, Gen. El. Co.). I believe double end locomotives, while characteristics are different, can be designed for high speed with safety equal to the single end locomotives, and this regardless of the height of the center of gravity.

ADAPTABILITY TO SERVICE CONDITIONS

The electric locomotive, besides being required to operate in either direction, is often required to be adapted for operating high speed passenger trains and heavy low speed freight trains over main line tracks, to negotiate sharp curves, and to be easy on light track and bridge structures.

With locomotives having geared motors, the requirement of operating the passenger and freight trains can often be met by changing the gearing to obtain the proper speed and draw bar pull.

The running gear can be made with trucks of short wheel base coupled together, the number of trucks depending upon the required weight of the locomotive for its maximum draw bar pull and also allowable weight per axle. With such a design, curves of very short radius can be operated over and the weight per axle can be such as to allow operation over light structures.

RELIABILITY OF SERVICE

When design is such that it is safe to operate at the required

speeds and is proper for the curves and other service requirements, and a liberal factor of safety is provided for the parts subjected to strain, the reliability in service depends mainly upon the bearings, their lubrication and the method of power transformation from motors to drivers. It is necessary, therefore, to provide effective lubrication, as few bearings, and as simple a driving mechanism as the design of the motors will allow.

After providing all Interstate Commerce commission safety appliances, it is important to arrange for the most convenient location of the operator to allow him an unobstructed view of the track and signals, to place within his easy reach the air brake valve and low-signal-device handle, as well as reverser and power controller handles, keeping in mind the importance of making them so free from complication that the operator will require the least amount of thought to manipulate any of the devices and be left free to respond to signals and look out for emergencies. Arrange housing of electric wire easy to inspect and repair, but protect against live wires.

POWER EFFICIENCY

The power efficiency as affected by the mechanical design is governed largely by the type of the traction motor.

It is apparent that the gearless motor mounted directly on the axle allows the design of maximum efficiency on account of its few bearings and absence of gearing and moving parts.

The gearless motor which is mounted on a quill and driving

through springs to the wheels may be considered second, it having additional bearings and a greater number of moving parts.

The single reduction geared motor with its extra bearing and gear losses third.

The single reduction geared motor driving through gears and side rods to wheels fourth.

Gearless motor driven through side rods and jack shaft to wheel fifth.

MECHANICAL EFFICIENCY

Bipolar gearless	100 percent
Quill drive	99 percent
Geared drive (twin gears).	95 percent
Geared to jack shafts and side rods . .	90 percent
Direct connected jack shaft and side rod	87 percent

COST OF MAINTENANCE

The cost of maintenance is dependent upon safety of operation, adaptability to service conditions, reliability, convenience of arrangement, quality of workmanship, ease of inspection of parts, and simplicity of design.

DEVELOPMENT OF RAILWAY MOTORS

The electric motor is but one link in the electric railway, yet it is of first importance. The motor receives the electric power and simply translates it into the requisite draw bar pull and speed.

The first general observation made regarding motors for use on freight and passenger cars was about in 1890 when one motor per truck was mounted on the first double truck electric car. About 1898, electric motor cars had become bigger and heavier, higher acceleration speeds were used and coaches were hauled. The service then required four motor equipments. Later imporvements in the direct current motor include commutating pole and slotting of mica between commutator bars.

Three phase motors were well developed before 1902 and few changes have been made since then. Single phase motors have been developed since 1904 and they have rapidly improved and are well perfected.

DEVELOPMENT OF RAILWAY MOTOR DESIGN

Railway motor design embraces machinery which furnishes the greatest possible output at the least expense in first cost and in performance. Motors have had to undergo many changes due to the many different conditions of demand on them.

Some of the details of development are:

Magnet frames of direct current motors were originally bipolar and of cast iron. Modern motors have used cast steel frames largely because the improved magnetic qualities of steel allowed a reduc-

tion in the weight and space. Box type frames were introduced about 1898. They have a single magnetic coating of soft steel, in the form of a cube with well rounded corners. Maximum capacity with minimum space together with rigidity of frame are obtained. Armature, field coils, and pole pieces can be removed through the end of the frame.

Enclosure of the entire motor has been finally effected. First it was protected by canvas or galvanized iron and then by the use of most of the magnet frame. An example of this was the famous waterproof motor of 1891. The covers over the commutators of small motors are closed, while the covers of large motors often have many half-inch holes. The axle is enclosed on the Pennsylvania motor cars to keep out the dust.

Poles of direct current motors were originally of cast or wrought iron or steel but are now of lanimated steel with magnetically saturated face bolted on the cast steel frame.

Commutating poles were developed about 1907. A small auxiliary interpole or commutating pole placed between the main poles holds the neutral point thus reducing the sparking.

Field coils with both shunt and series windings were found in the first direct current railway motors.

Armature of small motors was at first of large diameter and the armature winding had hand would surface coils. These have been superseded by machine wound coils with straight out barrel winding imbedded between teeth of a slotted armature. They are all formed and insulated before being placed in the core.

Commutators were originally of small diameter and poorly insulated but are now long, of large diameter, and have ample stock.

Brushes were originally of copper set at an angle with the

commutator. Van Depoele introduced carbon brushes in 1884. Good carbon was used as early as 1889.

Sparking at brushes is no longer destructive. The relation of the field magnatism to that of the armature is understood; and the use of the commutating pole in direct current motor and of compensating coil in single phase motor key the neutral point at the brush contact. The commutating pole motor has doubled the life of brushes. The New Haven brushes have a life of about 32,000 locomotive miles. (See El. Ry. Jl., June 19, 1909, p.1108).

Brush holder design has been perfected by the use of rigid supports. Longer creepage distance prevents flashing through the carbon dust.

Armature speed with the first motor was high. It has been reduced by modifying the magnet frames, increasing the number of pole and lengthening the armature core.

Gearing from 1888 to 1891 was double reduction and entailed high maintenance expense. Four pole motors introduced in 1890 allowed single reduction gearing. The ratio of gearing was changed from about 12 to 1 to 4 to 1. Pinions of raw hide, sheet steel, and bronze have been replaced by those of forged steel. Gears are now enclosed in gear case. Spur gearing seems to have been found much better than bevel gearing, worm gearing and hydraulically connected gearing, belts, wire rope, links and chains.

Gears are used at each end of the shafts on the Baltimore and Ohio, Great Northern, and New Haven locomotives.

Gearless motors are the popular type on many of the big General Electric constructed locomotives.

A gear may be in one piece, or split and of cast steel which may

be bolted, keyed, pressed, or shrunk, on either the axle or an extension of the wheel hub.

Pinions are now used which have great strength and uniformity of metal without sacrificing toughness.

SUSPENSION OF MOTOR

Suspension of motor was provided in the first motors by mounting them on the car floor and connecting them to the axles by belts, wire rope, or sprocket chains, and often through a friction clutch. A direct drive between motors and axles by means of gearing and crank rods was the outcome of the earlier method of connection.

The nose suspension was introduced in 1884. One end of the motor and half of the weight were supported directly on the axle bearings and the opposite or armature end rested on a cross bar, supported by the side frames of the truck. Nose suspension is the simplest and has superseded all others.

In 1890 Westinghouse motors introduced the cradle suspension. The entire motor was placed on levers or horizontal bars at each side of the motor and all the motor weight was transmitted to the axle and frame indirectly through springs. Two motors per truck were used and one motor balanced the other. Each motor formed a lever fulcrumed at the axle. This scheme became obsolete due to the higher first cost and the inaccessibility for repairs. (Burch--Electrive Traction).

General Electric motors of 1893 were using the side bar suspension. The side bars rested entirely on springs carried by the motor. One lug on each side caused the suspension to be through the center of gravity of the motors.

Yoke suspension was a modification in which the weight of the motor was largely suspended from points in line with the axis of the armature shaft.

The Walker spring suspension was introduced in 1895. It never was put into use, however.

In 1891 the London Railways tried gearless armature mounted directly on the locomotive axle but the plan proved to be a failure.

In 1895 the Baltimore and Ohio gearless locomotives used quill mounted armatures which were flexibly connected to the driver axle. The frame was spring suspended. New York Central gearless locomotives followed ten years later. Motor armatures, weighing 7640 pounds each, were mounted directly on the axle and the total dead weight, about 13,000 pounds per axle, was the same as the ordinary steam locomotive.

Quill suspension of armature involves the mounting of the armature on a hollow motor axle which encircles the driving axle, the inner shaft being held concentric with the outer shaft by means of spiral springs. (See Fig. 7).

Crank rods and jack shafts are discussed in the chapter on Types of Drives.

SYSTEMS AVAILABLE FOR ELECTRIFICATION

The development of electric traction system preceded an extensive use of electric power for railway train service. The commercial systems that have developed into use are

Direct current 600, 1200, 1500, or 3000 volts.

Three phase, alternating current 3000 or 6000 volts.

Single phase, alternating current 3000, 6000, 11,000, or 15,000 volts.

Combinations of these three systems have been developed.

The developments of direct current systems have given it the following classification. The potential between the trolley or third rail and track rails is usually 600 volts. This is used on most street railways, interurban railways, New York Central, New Haven, Pennsylvania, and long Island Railroads. Direct Current at 1200 volts is used, however, by about 15 American interurban railways.

The generation of energy for the direct current, 600 or 1200 volt system, for railway service, is not as direct current, but rather three phase alternating current; the latter usually being transmitted at high voltage then transformed to low voltage. It can be changed by rotary converter to direct current at 600 or 1200 volts in substations along the line of the railway.

The development of direct current began with 75 volts and soon jumped to 200 volts. In 1895 it increased to 600 volts which is now a standard in 95 percent of the railways in this country.

The 1200 volt, direct current, two wire system was first tried in 1907. This system requires doubled insulation at generator,

trolley wires, controllers, and commutators. Three wire systems are those in which the track is used as a neutral line, not for return of the main current.

Generation, transmission, transformation, and the use of three phase current at 15 and 25 cycle and 3000 and 6000 volts, followed the direct current system, for railway service.

Alternation with revolving fields and large transformers for high voltage had been developed in Europe by 1896. Tesla developed the three phase induction motor with and without collector rings. The development of a new system to utilize and adapt this equipment for heavy railroading soom became noticeable.

Siemens and Halke exhibited a three phase 600 volt 50 cycle 1400 r.p.m. 11 to 1 geared railway motor at the Chicago Exposition in 1893.

Italian railways and three Swiss railways used this system in 1898.

Ganz Electric Company made the first initial electrification of this system in 1902 for the Italian State Railways. This was a 15 cycle system of 3000 volts. It required substations placed six miles apart.

In September, 1902, the first real signs of a new single phase alternating current system became noticeable. The details of this new system had been developed largely by the Westinghouse Electric Company. This system marked a great advance in the struggle against economic limitations imposed by direct current systems on the transformation and distribution of power too widely separated, heavy indirect train units.

Single phase is used with 3000 to 11,000 volts and 15 to 25 cycle

alternating current. In America the 11,000 volt, 25 cycle system is most used. In Europe the single phase system has been widely adopted.

SUMMARY

The Prussian State, Swedish State, Swiss Federal, and Austria-Hungary Railroad Commissions have decided that the 11,000 volt, 15 cycle single phase system is best suited for traction on main lines, although direct current and the three phase systems have been found applicable under certain conditions.

The Italian State Railways favor the three phase system.

In conclusion it might well be stated that the direct current, 600 to 1200 rotary converter system can be best used to distribute and collect large amounts of energy for dense local traffic. The three phase system will give good results when low speed, heavy train service and regeneration of power on grade are combined.

The single phase system combines simplicity, flexibility, economy in power transmission, variable speed, and low cost for service.

The best system for train service is not one adapted to individual cases, but one which is adapted to the electrification of complete railroads.

COMPARISON OF EUROPEAN AND AMERICAN LOCOMOTIVES

A comparison of American and European locomotives shows a characteristic difference particularly in the method of transmitting the power from motor to driving wheel.

Continental designers have had little experience with heavy motor car equipment and were skeptical of gearing and mounting motors directly on the axle. Their efforts have been mainly directed toward substituting the electric motor for the steam cylinder, retaining all the side rods and perhaps adding a few more.

Continental motors show many variations of the side rod drive, both with the jack cranks direct driven by the motor through parallel rods and by means of gearing. Taking the most important trunk line electrifications in Europe and America, we find that out of nine European railroads operating 210 locomotives, there are 28 different types, while in America 14 railroads operating 364 locomotives there are but 21 types.

The design of electric locomotives for high speed passenger service at 60 to 80 m.p.h. is a complicated problem. With slow speed freight and passenger service the design of American locomotives has been influenced by the heavy motor car with direct geared motors. Gearless motors furnished a strong tractive effort with a very simple design. Passenger locomotives should be designed for double truck to save turn table construction, etc. A feature to control in double end locomotives is the lateral oscillation and to minimize its effect on the track.

For high speed passenger service with speeds of the order of 60 to 80 m.p.h., if a locomotive is equipped with geared motor, the gear reduction approaches a small ratio if the armature is to be kept within practical rotative speeds.

TECHNICAL OPERATING DEVELOPMENT

The progress of development in Electric Traction cannot be more forceably presented than by giving technical operating description of locomotives that are being used on our American Railways to-day. Seventeen years ago there were practically no electric locomotives for hauling even the simplest of loads. To-day there are electric locomotives far more powerful than any steam locomotive.

The development of electric traction has not yet reached its highest state of perfection -- rather it is still in its infancy and future development is just being given the foundation on which to work.

It would be foolish as well as absurd to believe that steam traction is doomed. Steam traction cannot be doomed because of the fact that steam traction is a part of transportation and financial world and it would be impossible to sever it.

Electric traction, on the other hand, is a coming thing. It is new but it will develop into a mighty channel of transportation. Perhaps it will give steam traction a stiff competition, but it should always be remembered that electric traction will be substituted for steam only when the financial and operating results justify its substitution.

Several American trunk lines have some exceedingly interesting and unique modern electric locomotives. A brief outline of the more important ones is given here.

TECHNICAL DESCRIPTIONS OF ELECTRIC LOCOMOTIVES

The Chicago, Milwaukee, and St. Paul Locomotive

The locomotive described here is now being used on the Seattle-Tacoma electric zone of the Chicago, Milwaukee, and St. Paul Railway. This is a 3000-volt direct current locomotive. This locomotive is entirely distinctive in design and possesses some very interesting mechanical and electrical features. It was built for passenger service. The locomotive is of the bi-polar gearless type with motor armatures mounted directly on the driving axles. In this feature

A 3000-Volt D. C. Passenger Locomotive for
The Chicago, Milwaukee and S. Paul Railway.

they follow the design of the New York Central locomotives. The chief advantage of this method of construction seems to be that of great simplicity of mechanical design. All gears, armature and motor bearings, jackshafts, side rods, or other transmitting devices are eliminated.

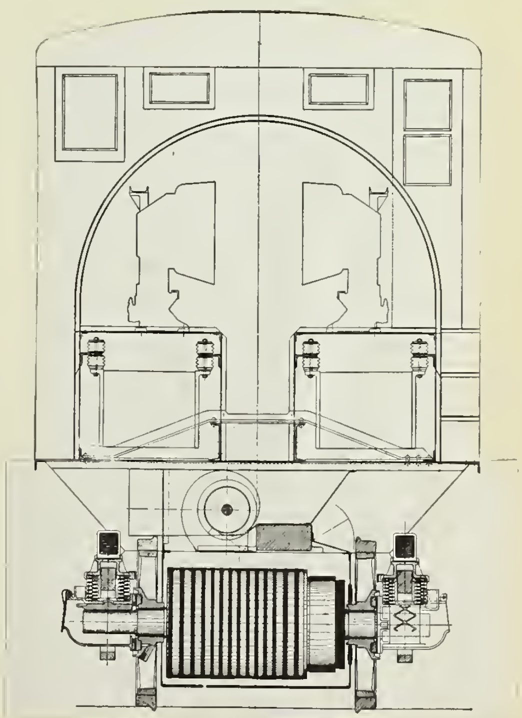
This locomotive weighs 265 tons with 229 tons on the drivers.

A side view of the locomotive.

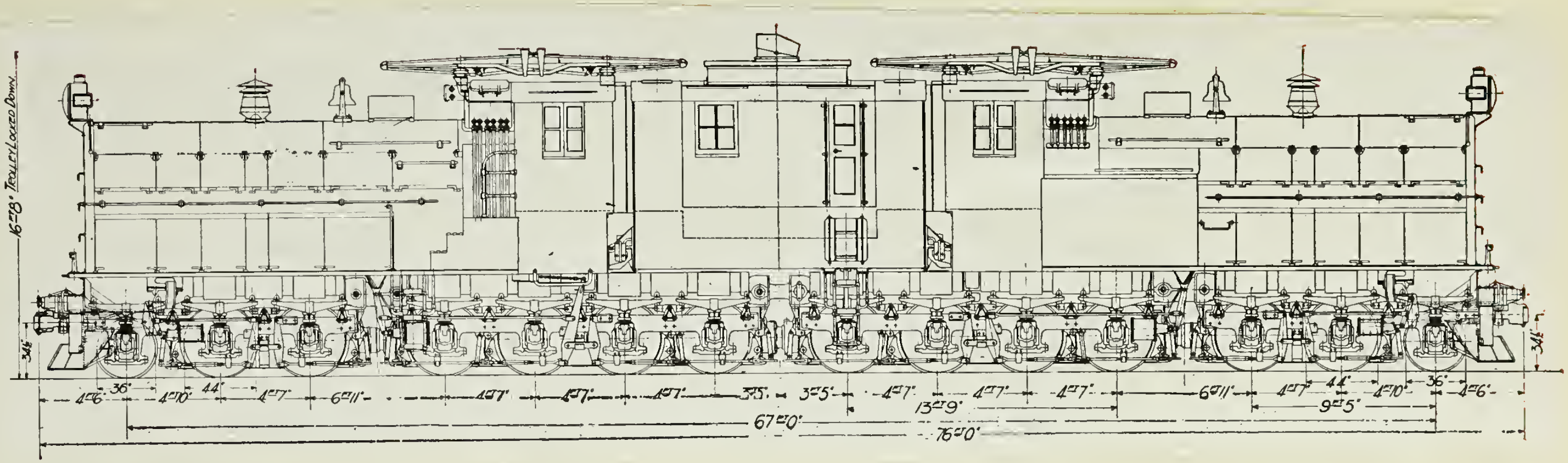
There are 14 axles, 12 of which are driving and two guiding axles. The only dead weight on the track is that due to the armature and wheels and this amounts to about 95000 pounds per axle. The total weight on the drivers is 86 percent of the weight of the locomotive, but, since it is distributed over 12 axles, there is but 38,166 pounds per axle.

A interesting feature in the design of this locomotive is the method of design of the trailing and leading trucks. The successive trucks are coupled together in such a way so as to beat or break up any lateral oscillations which may be caused by inequalities of track. The weight of the main cab is so supported on the front and rear trucks that any lateral thrust of the leading or trailing trucks against the track is cushioned by the movement of the main cab.

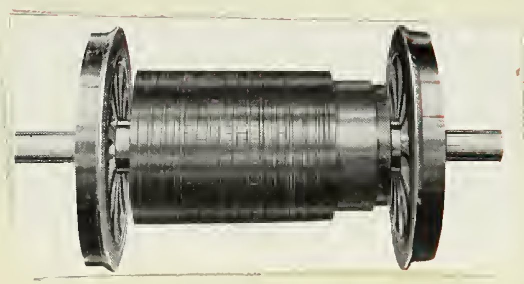
The locomotive is designed for handling in normal service a 12-car train weighing 960 tons, trailing against a grade of 2 percent with a speed of 25 m.p.h. This requires



Cross section of Apparatus Cab



Outline and Dimensions of the New D.C. Electric Locomotive.



Armature and Wheel.

56,600 pounds tractive effort.

The motor is bi-polar, two fields being supported upon the rack springs with full freedom for vertical play of the armature between the pole faces. For full speed operation, the twelve motors are connected three in series with 1000 volts per commutator. Control connections also provide for operating four, six, or twelve motors in series. The gearless locomotive shows a much better efficiency at high speed than the geared type, owing to the elimination of the gear drive.

From the diagram and photograph it will be seen that the running gear is composed of four individual trucks; two end trucks having three axles each and two center trucks having four axles each. These trucks are connected together by special articulation joints. The superstructure is made in two sections of similar design, with a third section between them. The third or central section contains the train heating equipment.

A 5000-Ton Freight Train.

For flexibility of surving, the running gear is made up of four trucks, each of a relatively short wheel base.

LOCOMOTIVE DIMENSIONS

Total weight	521,200 lb.
Total weight on drivers	457,680 lb.
Weight per driving axle	38,140 lb.
Dead weight per driving axle	9,590 lb.
Weight per idle axle	31,750 lb.
Dead weight per idle axle	3,560 lb.
Length overall	76 ft. 0 in.
Width overall	10 ft. 0 in.
Height over cabs	14 ft. 11 5/8 in.
Height over pantograph, locked down	16 ft. 8 in.
Total wheel base	67 ft. 0 in.
Maximum rigid wheel base	13 ft. 9 in.
Diameter of driving wheels	44 in.
Diameter of idle wheels	36 in.
Size of journals	6 in. by 13 in.
Dimensions of operator's cab	5 ft. by 10 ft.
Dimensions of heater cab	14 ft.11 in.by 10ft
Heater capacity	4000 lb.steam per hr.
Water capacity	30,000 lb.
Oil capacity	6,000 lb.
Compressor capacity.	150 cu.ft.per min.
Number of motors	12
Type of motor	(Bipolar-)GE-100
Diameter of armature	29 in.
Clearance between bottom plate and top rail . .	5 $\frac{1}{4}$ in.
Working range of pantograph	9 ft. 0 in.

BUTTE ANACONDA AND PACIFIC LOCOMOTIVES.

The locomotive equipment of this railway consists of 17- 80 ton units, fifteen for freight and two for passenger service. The freight locomotives are geared for slow speed and are operated in pairs for the main line service. The maximum free running speed is 35 m.p.h.

The two passenger locomotives are of the same construction as the freight units, but are geared for a maximum free running speed of 55 m.p.h.

The continuous tractive effort of a single 80 ton freight locomotive is 25,000 lbs. at 15 m.p.h. The maximum tractive effort of

Standard Train on Butte Anaconda & Pacific

the passenger locomotive for a period of five minutes is 48,000 lbs. This is based on a tractive effort coefficient of 30 per cent.

All these locomotives are of the articulated truck type with all the weight on the drivers. Twin gears are mounted on projections

provided on the wheal centers for this purpose, and in general mechanical design they are similiar to the locomotives of the Great Northern, Baltimore and Ohio, and Detroit River Tunnel Railway. The entire weight of the locomotive is carried on semi-elliptic springs suitably equalized.

Pantagraph on Single Wire

Each unit is equipped with four commutating pole motors, wound to operate at 1200 volts each but insulated for 2400 volts. The horse power of each motor is approximately 300 H.P. This makes their hourly rating of each unit about 1200 H.P. These motors were designed for locomotive service and are provided with forced ventilation. The air is circulated by an auxiliary blower.

The gear reduction on the passenger locomotives is .2 and on the freight is 4.84. The double unit 160-ton locomotive is capable of giving a sustained continuous output of 2100 H.P.

The controller provides 10 steps in series and 9 in series-parallel. The 2400 volt contactors are operated from the 600 volt control circuit.

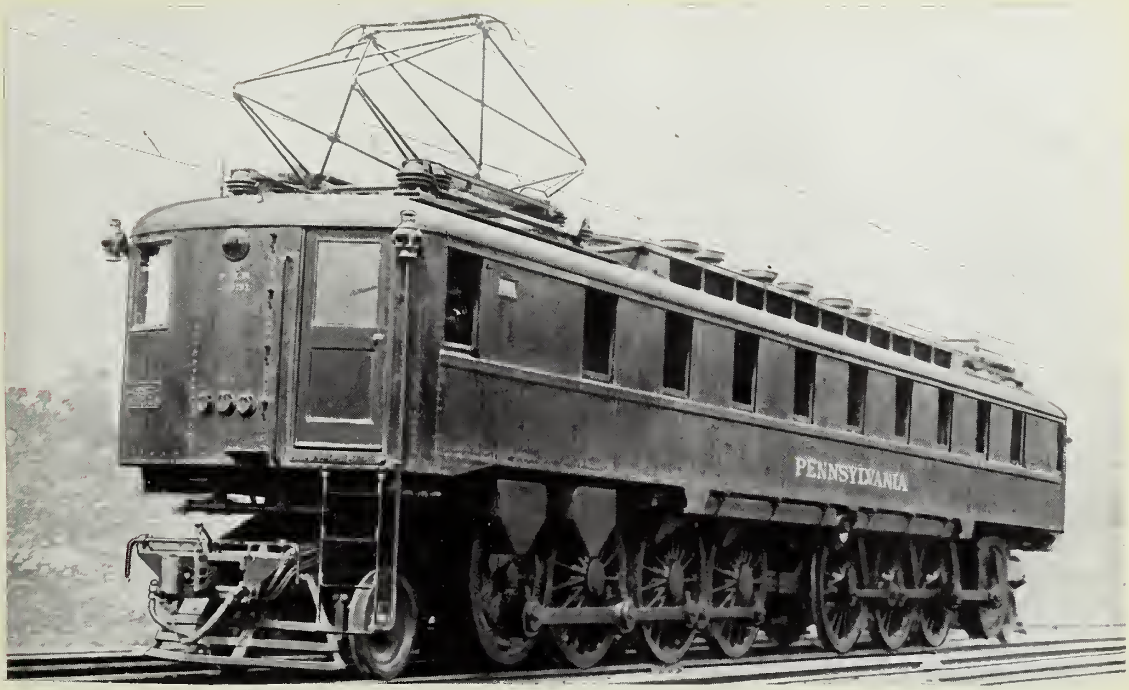
Current is collected by overhead roller pantograph as shown in the figures here. They are pneumatically operated from the cab and insulated along the center of the cab roof.

Pantagraph engaging six overhead wires together

Pennsylvania Railroad

One of the latest types of electric locomotive that will show the great strides made in this development is now used on the Pennsylvania Railroad between Altoona and Johnstone, Penna.

It is similiar to the locomotives of the Norfolk and Western Road, in that its power is supplied by three phase induction motors, fed thru a transformer and phase converter from an 11,000



New Pennsylvania Locomotive

volt single-phase trolley wire. It has a rating of 4800 H.P. in a single cab. The complete locomotive ready for service weighs 250 tons and has an overall length of 76 1/2 feet. Compare this with the first electric locomotive that was scarcely larger than automobile that children play with. The locomotive is capable of exerting 130,000 pounds tractive effort (equivalent to 7000 H.P.) in starting. Westinghouse engineers have estimated that with two

of these locomotives, it will be able to haul a 3900 ton train up the 12 mile eastern slope and a 6300 ton train up the 24 mile western slope of the Pennsylvania Railroad at 20.6 m.p.h.

The locomotive is designed for regenerative braking and the cab design gives the locomotive great flexibility. The flexible gear is used with a gear face ten inches wide. The leading truck is a two wheel swing bolster type and each main truck has a three-point equalization.

This locomotive was described in order to bring out the extent of the development of Electric Traction. Imagine such a powerful giant to be evolved out of a evolution lasting little more than twenty-five years.

Running Gear for Pennsylvania Locomotive

The New York, New Haven, and Hartford Railway

The New York, New Haven, and Hartford Railway has one of the most densely populated lines of any railroad in the world.

They run four tracks abreast to handle their traffic. Two tracks are used for freight and two for passenger service.

The traffic on the New Haven road became so dense that electricity was decided on to be the solution of their traffic problems. Since the adoption of electricity there has been no traffic delay or hold-up on any part of the line.

The locomotives used on the New York, New Haven, and Hartford railway are all operated on 11,000 volts A. C. The passenger locomotives are geared for extremely high running speed, this line having the highest scheduled speed of any trunk line railway .

The locomotives are so designed that they can be operated from D.C. current as well as A. C., since they must enter the New York terminal over a D.C. electrification.

In the New York, New Haven, and Hartford railway the extent of the electrification field can be seen.

Electric locomotives are solving their transportation problems and helping their traffic departments. Electric traction has taken a firm hold on this railway.

Of the seventy through trains per day, thirty-six are electrically operated the entire distance. The thirty-four other trains having steam operation into New Haven terminal.

Forty-eight A.C.- D.C. locomotives are used and twenty-five A.C.- D.C. multiple unit cars with trailers constitute the elec-

tric motor equipment needed to handle their traffic.

The average number of train miles per day,electrically operated is sixty-six hundred. The multiple unit cars make an average of twenty-one hundred miles per day.

New York Central Railroad (Hudson River)

The New York Central Railroad has found that electric locomotives can handle traffic easier and faster than the steam locomotives used before. A brief description of the locomotives that have been used is given here. This line has an interesting and unique electrification and should prove a good subject for study.

The New York Central electrification is 600 volt D.C., covering 37 miles. The locomotives are the gearless type as used on the Milwaukee locomotives. They are geared to run 60 and 65 miles per hour.

Latest Type Gearless Locomotive on New York Central

The great capacity of electric locomotives can be better understood when we consider this locomotive. Under ordinary conditions it can haul a 336 ton, 8 car train at 63 miles per hour with an average acceleration of .6 M.P.H.P.S.

It can haul a 170 ton train at 72 miles an hour.

Norfolk and Western Railway

The Norfolk and Western Railway are using electric locomotives on their division between Bluefield and West Forks, Virginia. The train service consists, for the greater part, of gathering coal. This coal hauling amounts to 2000 carloads each day. Besides this regular passenger service is maintained. The electric locomotives on the Norfolk and Western Railway have proved that they can better handle the service than the steam locomotive. This is another indication of the completeness of the evolution

Norfolk and Western Heavy Tonnage Locomotive.

of the electric locomotive and electric traction. Twelve locomotives are used here. They are of the Baldwin-Westinghouse make.

Each unit consists of two identical parts. There are two guiding and two driving trucks. The trucks are placed back to back, making the classification 2-4-4-2.

The development of Electric Locomotive design is forcefully presented when we look at the size of the locomotive wheels. There are 62 in. drivers and 30 in. guiding wheels. There is 22 ,000 lb on the drivers and the weight of the total unit is 27 ,000 lbs. The length of the locomotive is 105 ft. 8 in. There are four three phase adjustable motors mounted on the trucks. The total tractive effort of the locomotive is 125,000 lbs.

Heavy Tonnage Train on Grade.

When we look at these massive locomotives that are being used to-day it is easier to understand the extent which the development of Electric traction has attained. A complete description and story of the successes and uses of Electric Traction on this railway can be found in any of the trade publications and will prove interesting and well worth reading. It is not the purpose of the thesis to go into detail regarding the different railways but only to show the kind of locomotive used in order to more forcefully present the progress made in this field.

Engine replaced by Electric Engine.


New York Central R. R.

Canadian Northern Ry.


Chicago, Milwaukee & St. Paul Ry.


New York Central R. R.


Chicago, Milwaukee & St. Paul Ry.


Chicago, Milwaukee & St. Paul Ry.


Boston Elevated Ry.

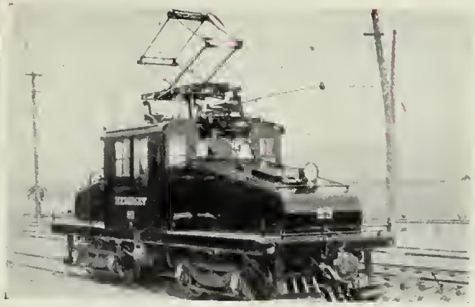
Fort Dodge, Des Moines & Southern R. R.


Philadelphia Rapid Transit Co.

Chicago Elevated Ry.

Great Northern Ry.

Interborough Rapid Transit Co.



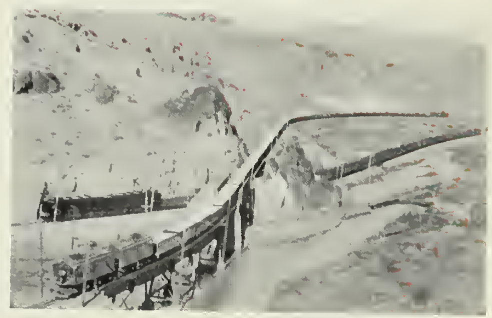
Hershey Cuban Ry.

Butte, Anaconda & Pacific Ry.

Bethlehem Chile Iron Mines Co.

Michigan Central R. R.

Michigan Central R. R.



B. A. & P. Ry. and C. M. & St. P. Ry.